

Battery Prognostics for Enhanced Combat Vehicle Readiness and Reduction of Total Ownership Costs



USMC Light Armored Vehicle
LAV-25

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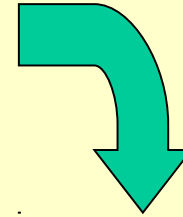
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- Needs for Battery Monitoring
- Available Technology Comparison
- Model-Based Battery Prognostics
- Operational Implementation
- Operational Risk Management
- Impact to Life Cycle Costs

New Capability Available to the Warfighter

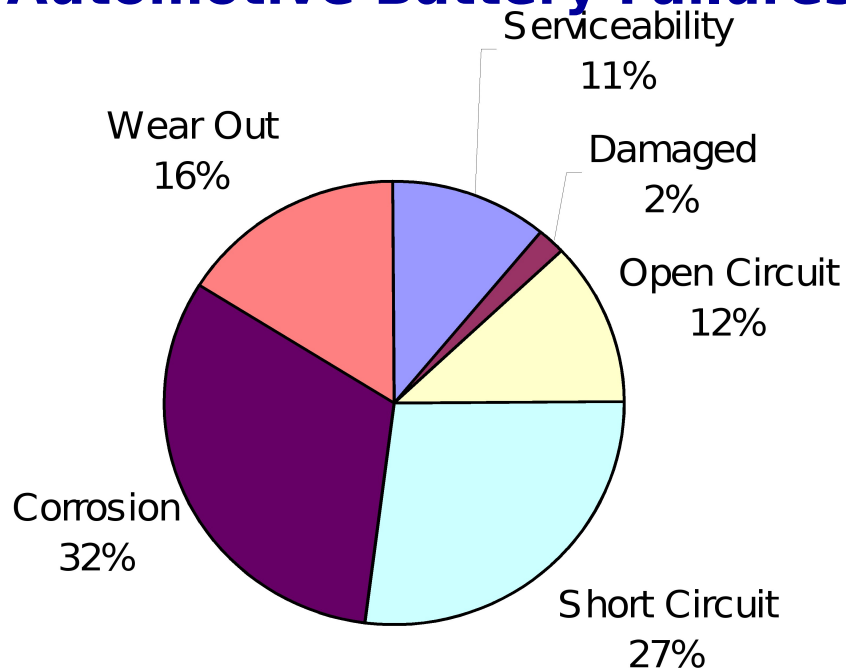
- **Will the battery crank the engine?
How Many more times?**
- **Before I shutdown, is the battery ok?**
- **I'm on silent watch, how much longer
can I go and be sure I can restart?**
- **This battery has been in storage, is it
still good and charged?**
- **What's the electrical problem- the
alternator or battery? Which
battery?**



**Prognostics
Information to:**

- **Operator**
- **Maintainer**
- **Log/supply**
- **PM**
- **Command/C
trl**

Failure Modes as a Percentage of Total Automotive Battery Failures



“Batteries for Automotive Use”, P. Reasbeck and J.G. Smith

Present

Solutions: Carry backup or reserve batteries

- **Over-design batteries to reduce use and time between failures**

Heavy, costly

New Alternative
Use an online battery monitoring system to detect and predict impending faults and assess available power and usage time

Why not just use off-the-shelf battery monitoring products?

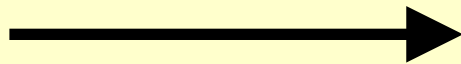
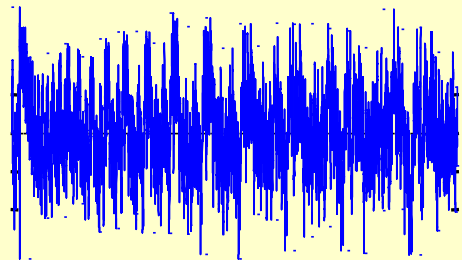
- **Open-Circuit Voltage :** accuracy
- **Discharge Test :** time and equipment
- **Coulomb Counting:** need full discharge
- **Temperature:** harsh environment

Standard Technologies:

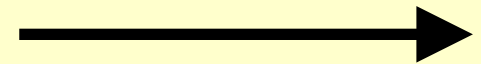
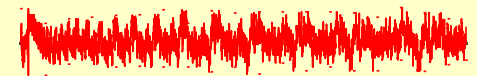
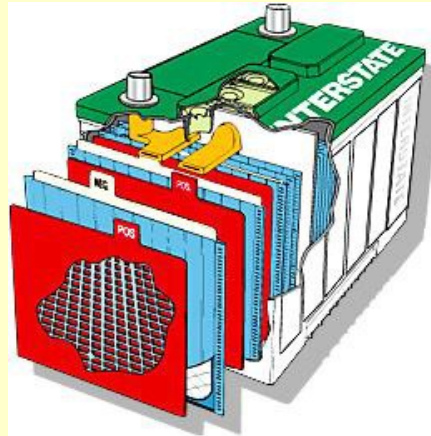
- Commercial State of Charge (SOC) technologies use a very simple measurements of voltage, current, temperature and internal impedance.
- Voltage Monitoring: Compares voltage to SOC table.
 - Measurements must be made off-line and drop off voltages are difficult to measure accurately.
 - Coulomb Counter: Measures total amount of current in/out of battery.
 - Low accuracy due to battery self-discharge and temperature variations.
 - Internal Impedance: Measurements are based on impedance values at a few frequencies.
 - Models are highly frequency dependant so SOC estimates have 10% - 20% error.
 - Limited State of Health (SOH) and State of Life (SOL) information available with these methods.

Impedance Interrogation Technology:

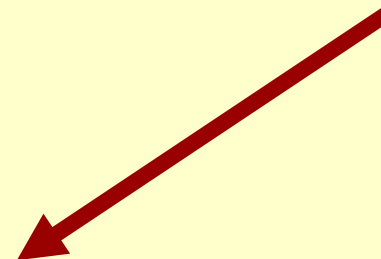
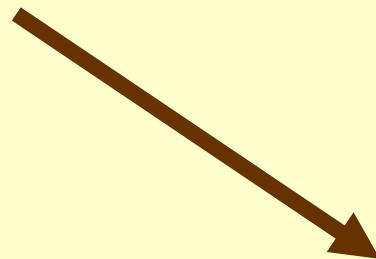
- Uses patented complex impedance measurement to estimate SOC, SOH and SOL on-line.
- Impedance measurement covers broad range of frequencies.
 - High resolution impedance image creates accurate model for analysis.
 - SOC prediction: 1% to 2% error
 - Fuzzy Logic, Neural Network and ARMA models with decision fusion algorithm.
 - Multiple predictions provides a higher level of performance and increased confidence.
 - SOH provides classification of the failure mode.
 - Improves prognostic capability
 - SOL - remaining useful cycles prediction is dependant upon accurate failure mode identification.



Excitation IN



Response OUT



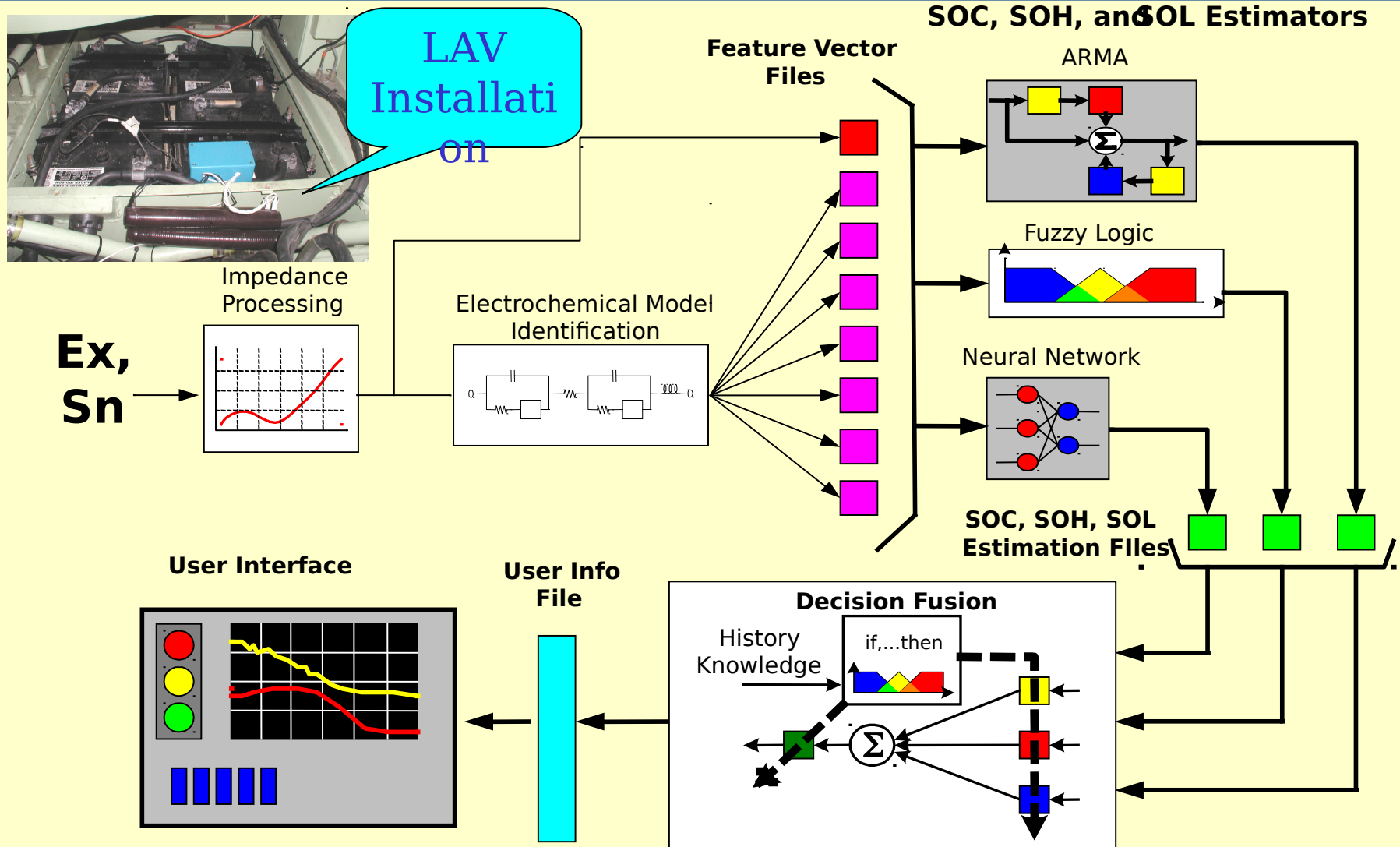
**Characteristics of
Internal Condition and
Activity**

Yes, but...

**There is a lack in performance for *both*
measurement techniques and
processing of the information**

And therefore...

**There is a *perception* that
impedance-based technology
cannot effectively assess the
condition and health of a battery**



Training and Testing Results from SLI Lead-Acid Battery Set (-10 to 50 degrees C)

Test	ARMA error	N.N. error	Fuzzy error
No Load	7.08%	3.41%	7.90%
ISOC	3.07%	3.15%	3.52%
CSOC	1.52%	2.96%	2%

Tactical Use of Battery Prognostics

- Gives broadest range of tactical information before, during and after mission:

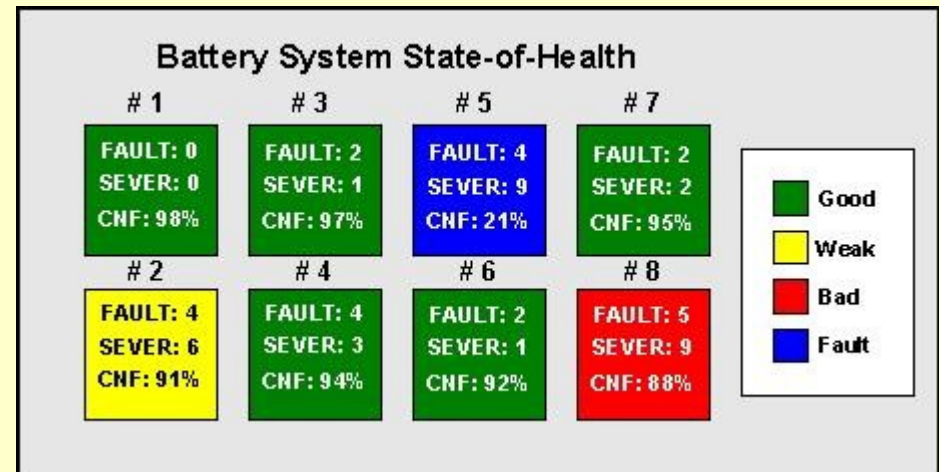
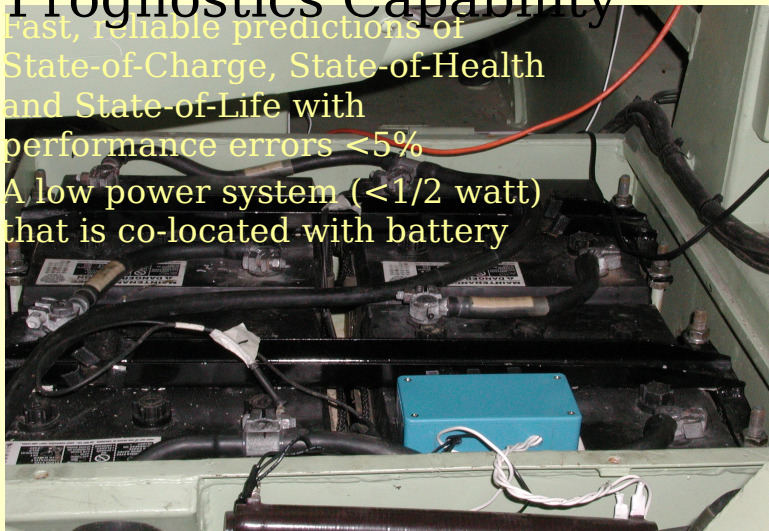
- State of charge: ready to start
- State of life: condition during use
- State of Health: readiness for future mission(s)

- Applies to huge range of battery types, sizes and uses

- Example of True Prognostics Capability

- Fast, reliable predictions of State-of-Charge, State-of-Health and State-of-Life with performance errors <5%

- A low power system (<1/2 watt) that is co-located with battery



Battery Charge Level: 85%

Usage Time for System Under Battery Power:

Min: 38 hrs. Nom: 20 hrs. Max: 50 min. Current: 27 hrs.

Engine Cranks without Recharge: 8

Remaining Engine Cranks at Full Charge: 105

Conditions:

Battery #2 has a potential short forming

Battery #5 is in a weak state



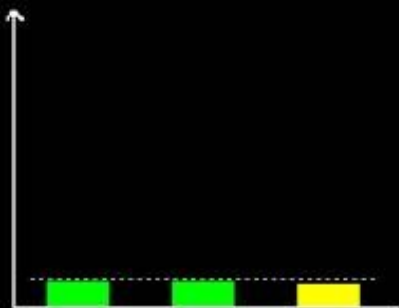
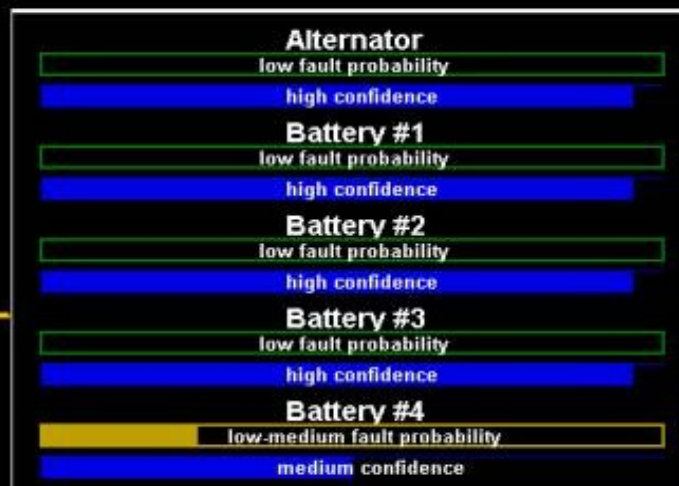
Engine

Power Train

Electrical System

Pneumatic/Hydraulic

VEHICLE HEALTH MANAGER



Diagnostic Status

Battery charge is below minimum. Continue mission

MANAGING OPERATIONAL RISK WITH BATTERY PROGNOSTICS

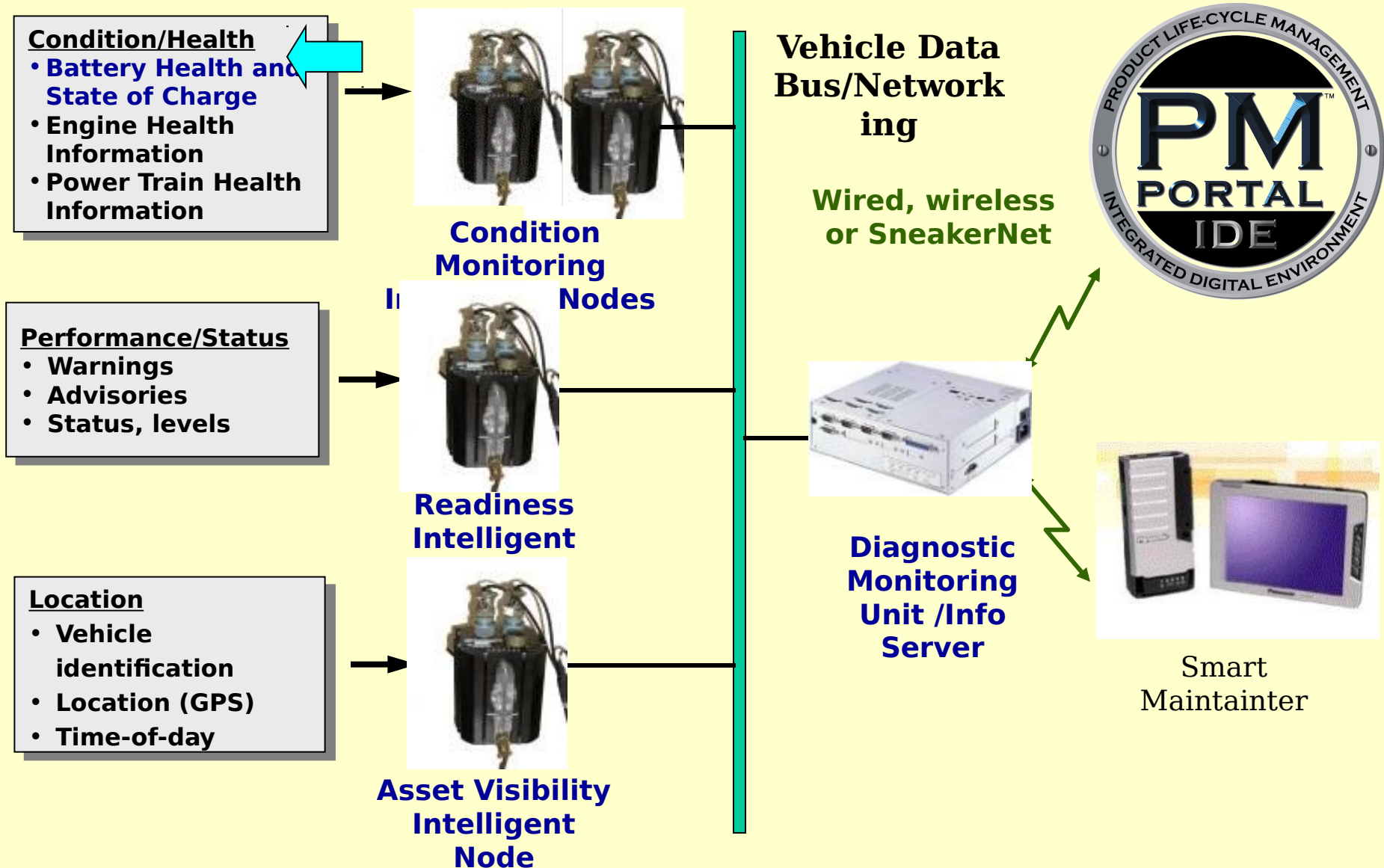
User interface describing state of battery health, life and charge to the operator.

Information presented before operation (availability) and during operation (maintaining op tempo and managing operational risk)

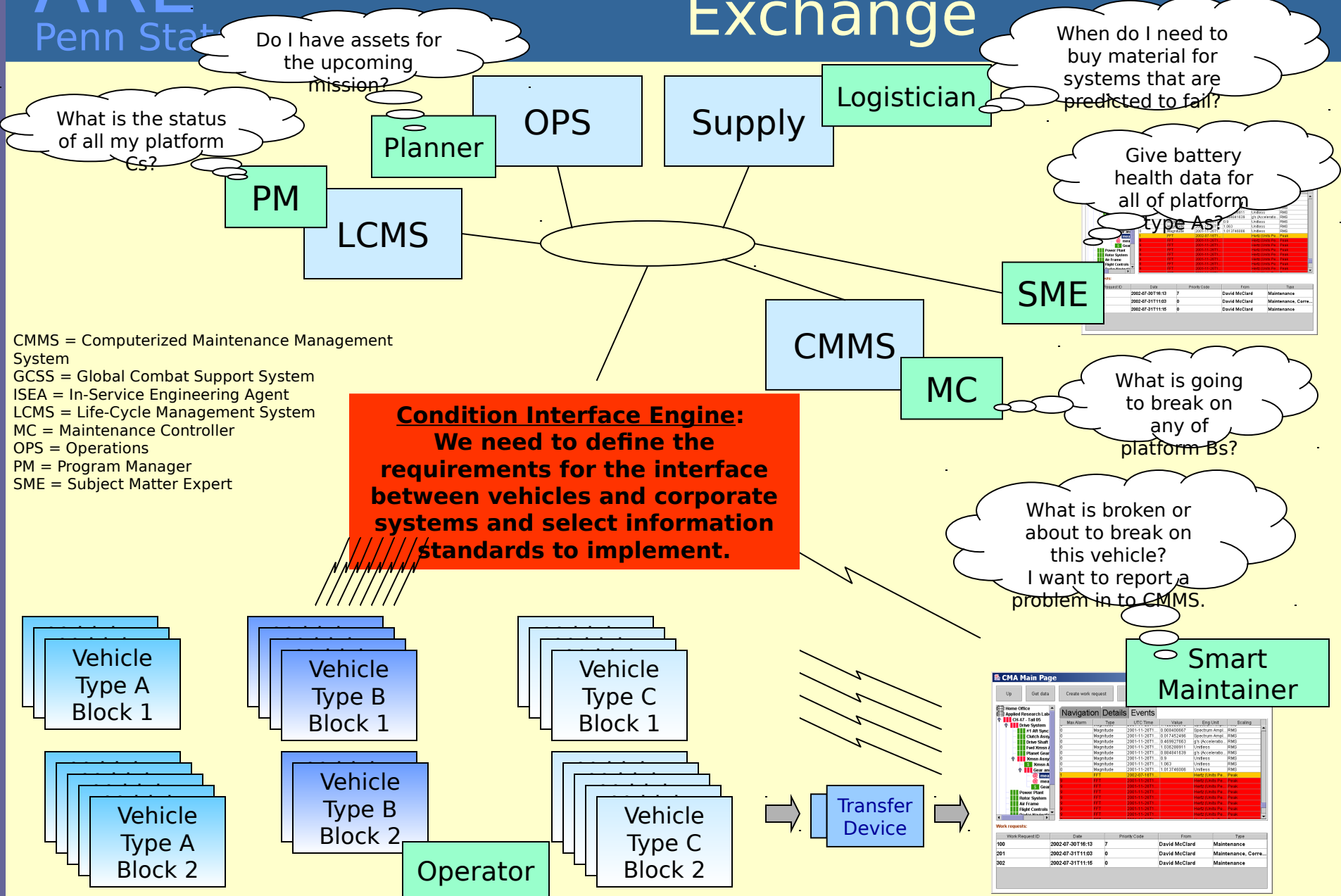
Fault failure information provided to



Tactical Combat Vehicle System Layout



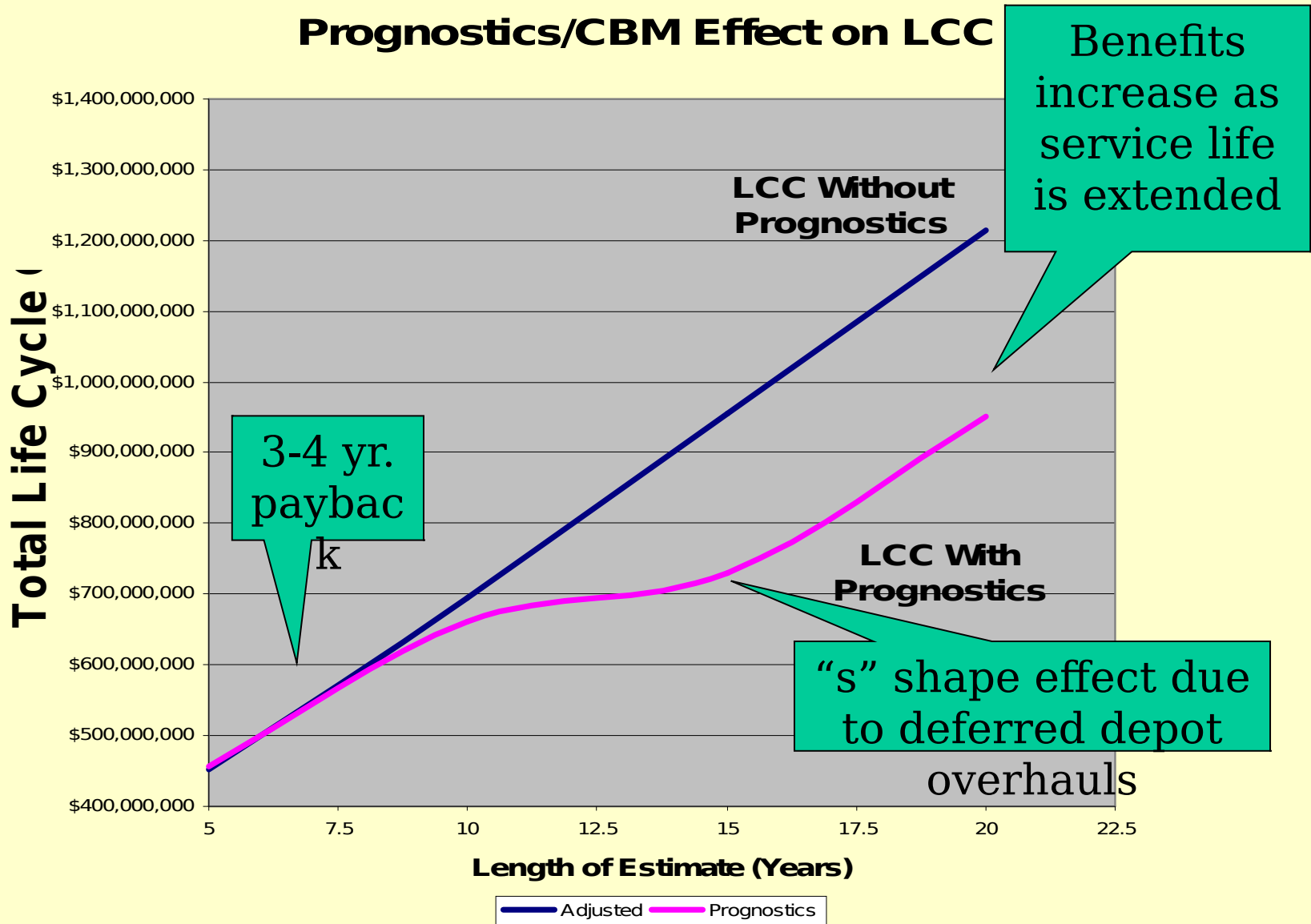
Platform Status Information Exchange



Benefits of Battery Prognostics

Benefit Category	Impact of Battery Prognostics	Benefits to All Vehicles Using 6TL Battery Types (P/A)
Operational Availability -Eliminates unanticipated failures-to-start -Enables management of battery power during silent watch	-confirms state-of-charge and state-of-health prior to attempted start -provides state-of-charge and remaining useful life during silent watch	513,488 lost hours (out-of- service time)
Maintenance - Isolates fault to a specific battery -Confirms good condition of battery (visa electrical system problem)	-Stops unintended replacement of good batteries -Stops the practice of replacing battery farm when only one is bad -Prevents unnecessary battery removal as part of electrical system diagnosis -Identifies battery mode of failure and indicates cause	\$2.698M per year
Log/Supply -Reduces number of batteries in inventory	-Extended life of batteries -A priori determination of need for battery replacement	\$5.565M

Cost/Benefits Top Level- AAV RAM/RS Studies



Top Level- EFV (AAAV) Increased Operational Availability

AAV RAM/RS Data (Hours)		W/O Prog	W/Prog
Mean Time Between Failures		64	73.6
Mean Time To Repair			0.87
Mean Logistics Delay Time			2.7675
Increase in Operational Availability As a result of CBM+			
AAV RAM/RS Calculations		W/O Prog	W/Prog
Forecasted Op Availability		91.08%	95.29%
Increase in Op Avail w/Prog			4.21%
Increased AAVs Mission Capable w/Prog			29
Total LCC Costs per AAV w/Prog			\$973,504
Operational Availability			
Opportunity Benefit of Prognostics			\$27,890,754

Benefits can either be: increased Ao; decreased life cycle cost or reduced number of assets for same total operational availability

SUMMARY

- Battery Prognostics is Real
- High accuracy over present techniques
- High value added to the warfighter
- Enabling capability to manage operational risk, increase operational readiness and reduce life cycle costs

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